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**Selection of Power Requirements for
Nuclear-Electric Spacecraft Missions**

Jerry P. Davis May 24, 1961

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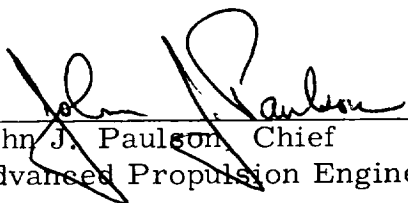
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National Aeronautics and Space Administration
Contract No. NASw-6

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SELECTION OF POWER REQUIREMENTS
FOR NUCLEAR-ELECTRIC
SPACECRAFT
MISSIONS

Jerry P. Davis



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ABSTRACT

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This paper presents a means for bracketing propulsion power requirements for spacecraft missions consistent with specific launch vehicle boost constraints and anticipated state-of-the-art reactor-conversion system development.

A Mars orbiter mission is taken as an illustrative example of the basic approach. Having selected launch vehicle, payload, and flight time, the distribution of powerplant and propellant weight is discussed. Curves are presented which indicate the minimum power requirement for the mission, the power range which affords maximum powerplant design flexibility, and the powerplant specific weights which must be attained to accomplish the mission. The interplay between mission requirements and powerplant development is indicated.

The paper concludes with the indication that a nuclear electric plant in the power range of 100 Kwe propulsion at a specific weight in the range of 35 lb/Kwe can accomplish a useful Mars orbiter mission in a reasonable flight time and delivering a useful scientific payload.

Data are also presented for two Jupiter missions.

I. INTRODUCTION

In discussing power requirements for nuclear spacecraft missions with various reactor and conversion system designers, one becomes aware of the need for a definitive approach to the sizing of such plants.

The most frequent question put to the spacecraft designer is that of power requirement for a particular mission. The significance of 30 Kwe, 60 Kwe, 300 Kwe, and 1 Mwe (those most-discussed "milestones" in reactor evolution) is open to question. Are these really the power levels desired for the missions of greatest interest to the spacecraft designer? How does one go about selecting a power level for a given mission?

This Report attempts to present one means of bracketing power requirements consistent with specific launch vehicle boost constraints and anticipated state-of-the-art reactor conversion-system development.

II. LAUNCH VEHICLES

Prior to the selection of any particular mission and associated time schedule, it is prudent to investigate the launch capabilities which should exist during this decade. These capabilities are tabulated as follows:

<u>Vehicle</u>	<u>Total weight in 300 n. mi. orbit</u>	<u>Availability date</u>
I	8,800	1963
IA	15,000	1964
II	45,000	1965
III	300,000	>1969

"Availability date" in the tabulation merely notes that such a vehicle should be in existence at that time, not necessarily that the vehicle would be available for a given mission. For reactor-conversion system designers, however, it is as good a starting point as any.

III. MISSION

As an illustrative example we have considered a Mars orbiter mission utilizing Boost Vehicle I. The mission commences from a 300 n. mi. Earth orbit and terminates in capture of the planet T_0 days later.

The mission consists of three phases: (1) a slow spiral out from the initial Earth orbit to Earth escape, (2) a heliocentric transfer from the Earth's orbit. The two planetary spirals are performed with constant tangential thrust. The propellant needed for the heliocentric transfer trajectory is determined from an optimal, variable-thrust and variable-specific impulse program,¹ which minimizes the amount of propellant consumed for a given transfer time.

An arrival weight (exclusive of the reactor conversion system) of 3000 lb was selected as a reasonable minimum desired. This weight includes ion engine, structure, communications, hardware, guidance and control, instrumentation, and scientific experiments. This weight is not considered the absolute minimum necessary for performance of the mission, but does represent a number below which grave compromises in mission reliability and/or usefulness must be made. Thus,

¹W. G. Melbourne, Interplanetary Trajectories and Payload Capabilities of Advanced Propulsion Vehicles, Technical Memorandum No. 312-76, Jet Propulsion Laboratory, Pasadena, January 5, 1961.

starting with 8,800 lb lifted into orbit, 5,800 lb is available for reactor conversion system and propellant.

IV. ANALYSIS

Having selected a combined powerplant propellant allowance, the problem of distribution must now be attacked. Unfortunately, the relatively simple type of optimization of propellant-to-powerplant ratio based on a given velocity increment does not give the finest representation of either the best distribution or the effect of moving away from the best distribution. In general, the specific mission must be analyzed to gain the maximum information

Figure 1 represents the relationship between maximum allowable powerplant weight and electric power delivered to the ion engine. Flight times of 200 days (pretty fast), 400 days (reasonable--a little on the slow side), and 600 days (too slow) are parametrically represented. Each curve, being fixed time and payload, can be thought of as an equiperformance representation. One characteristic of these curves worthy of noting is the rather obvious fact that even a zero weight powerplant of finite power capability is not sufficient to perform a mission if that power level is not sufficient to supply the required energy to the available propellant.

By use of Fig. 1, a plot of maximum powerplant specific weight vs power can be obtained, as shown in Fig. 2. As longer and longer flight times are selected, the specific powerplant weights may be higher, as would naturally be expected. What is not so obvious without the aid of the graph is the relatively rapid narrowing of the power range which affords maximum powerplant design flexibility, i. e., higher permissible specific weights as flight time is increased. It is possible, for example,

to bracket the power range of interest for a 400-day-3000-lb payload Mars orbiter to 75-125 Kwe with maximum allowable spacefic weights of 40 lb/Kwe at the lower power to 32 lb/Kwe at the higher power. Lower specific weight powerplants in this power range could naturally afford higher payload capabilities and/or shorter trip times.

Another useful outgrowth of this type of examination is the ability to compare mission weight-power requirements with powerplant weight-power relationships to further narrow the range of interest. Figure 3 is a reproduction of the 400-day curve of Fig. 2 with a hypothetical powerplant specific weight vs power curve superimposed. It is now possible to answer the question of whether, for this particular mission, a 150 Kwe, - 30 lb/Kwe plant is more desirable than, say, a 100 Kwe, - 34 lb/Kwe. Inspection of the curves indicates the desirability of the lower-power --higher-specific-weight plant.

Figures 4 through 7 indicate the results of this analysis for a Jupiter capture mission. For a 600-day trip utilizing Booster IA and a 5000-lb gross payload, about 350 Kwe at 13 lb/Kwe is required. For the same trip time utilizing Booster II and a 15,000-lb gross payload, about 1.0 Mwe at 13 lb/Kwe is required.

V. CONCLUSION

The curves shown in the figures, while resulting from an actual mission analysis, have not been carried to a high degree of accuracy and are included as illustrative of an approach, rather than for their precise quantitative content. They do indicate, however, that a truly useful Mars orbiter mission may be accomplished in a reasonable time with a reasonable payload utilizing nuclear powerplants with

outputs in the order of 100 Kwe having specific weights lower than about 35 lb/Kwe. Jupiter missions with trip times on the order of 600 days require plants in the range of 13 lb/Kwe and power levels in the range of 350 Twe and 1.0 Mwe for gross payloads of 5000 and 15,000, respectively. We are presently engaged in the generation of several power, specific weight, flight time, payload analyses of this nature for various missions and launch vehicle boost capabilities.

ACKNOWLEDGEMENT

The author gratefully acknowledges the assistance of Mrs. Evelyn W. Speiser in performing the mission studies referred to in the foregoing report.

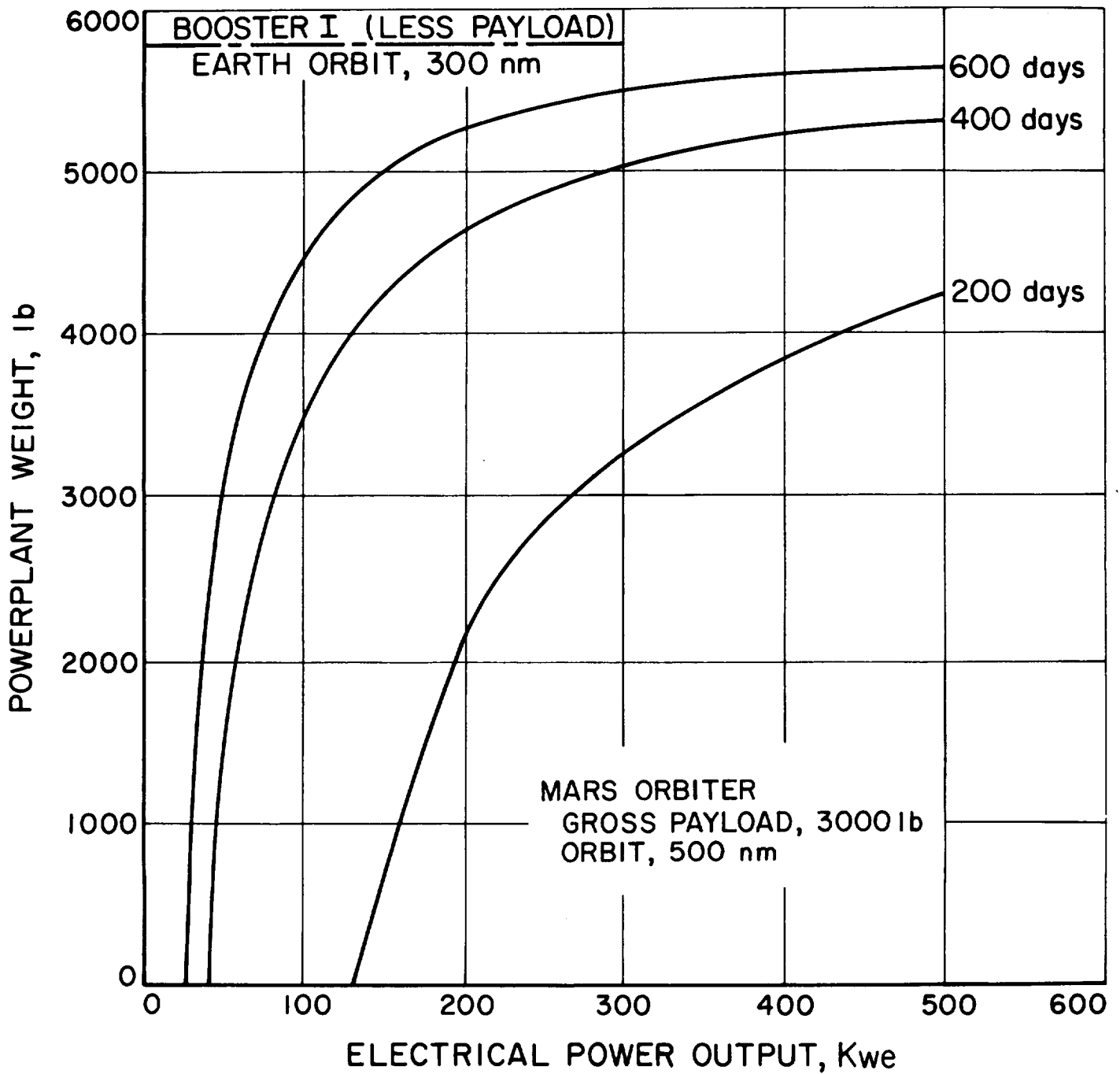


Fig. 1. Electrical powerplant requirements to deliver a powerplant payload of 3,000 lb at Mars, using booster I

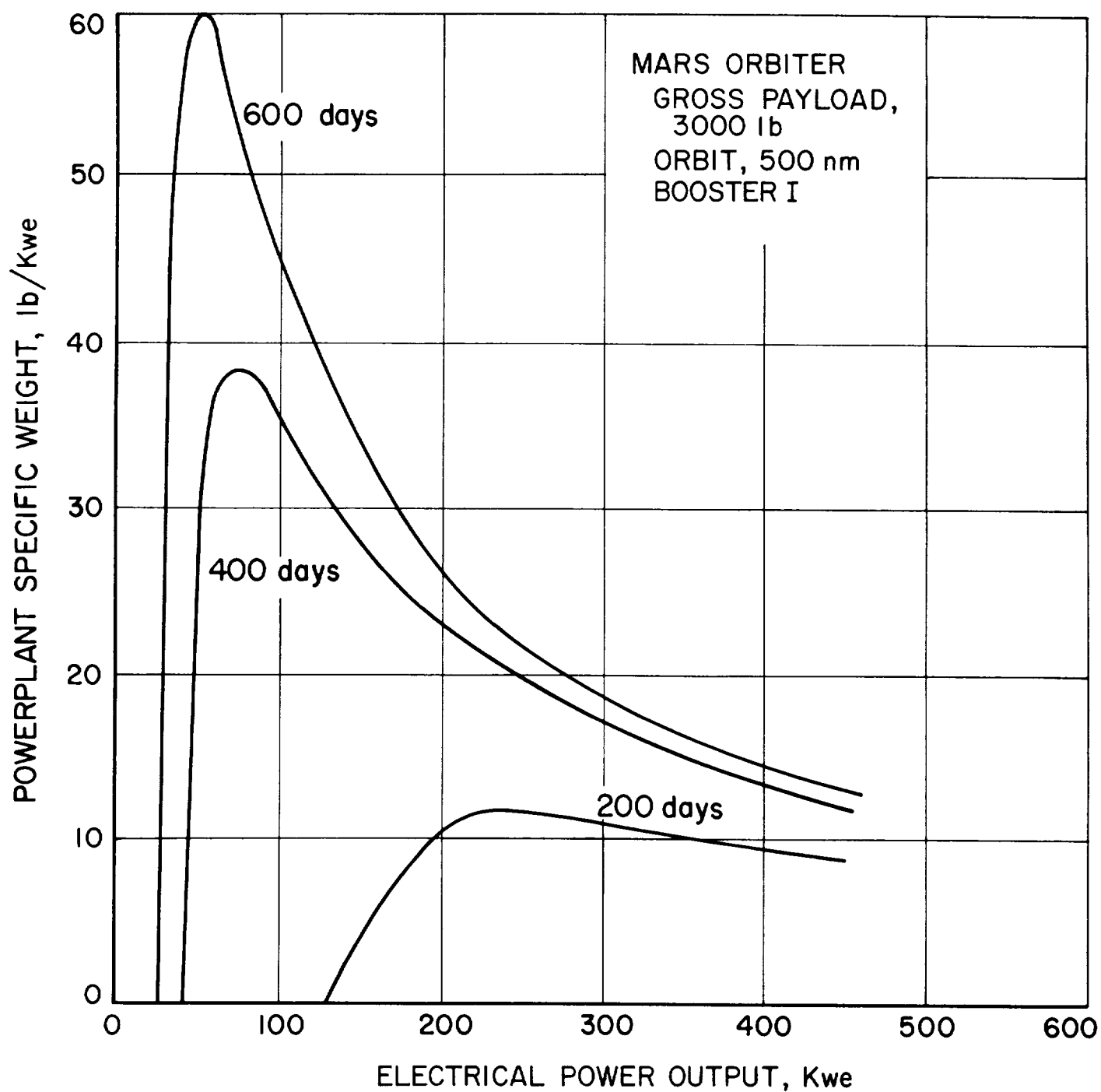


Fig. 2. Electrical powerplant requirements to deliver a powerplant payload of 3,000 lb at Mars, using booster I

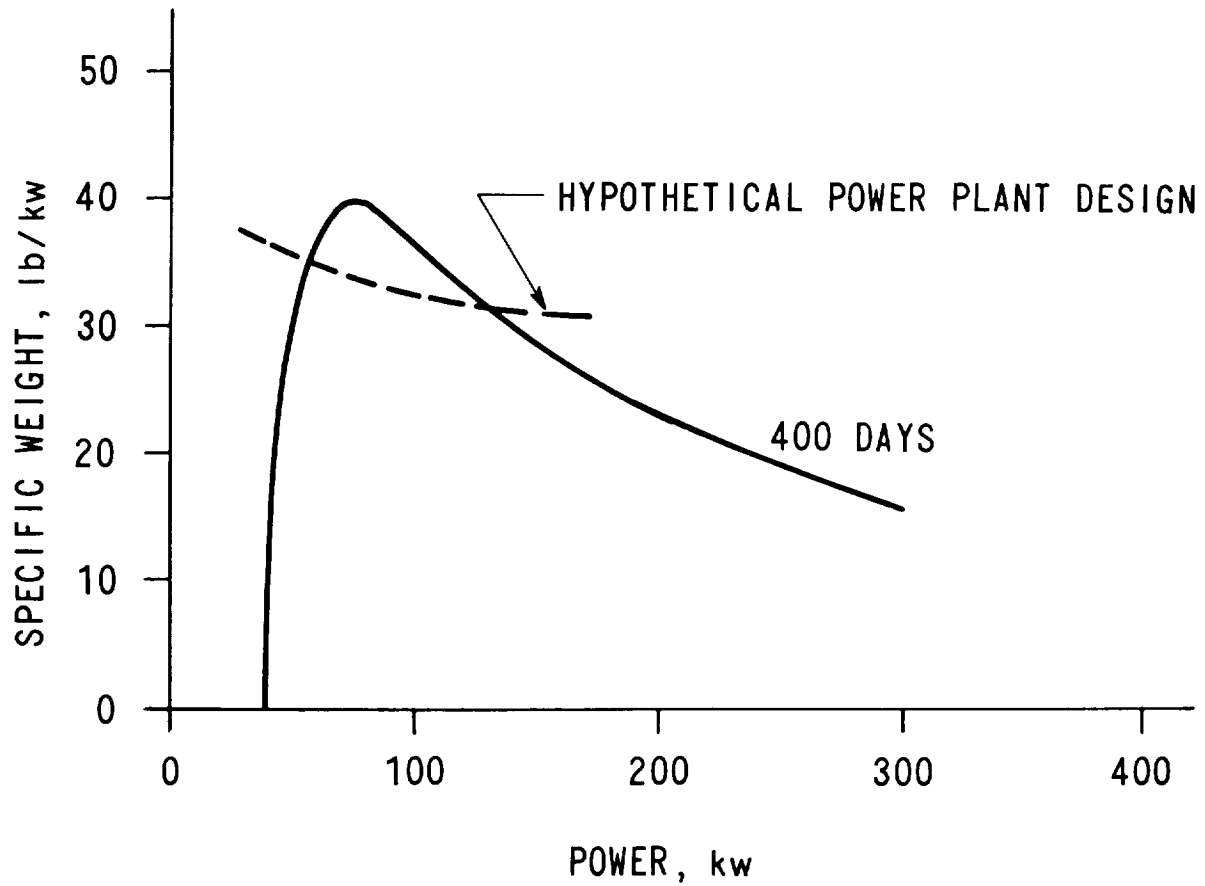


Fig. 3. Mission vs power plant

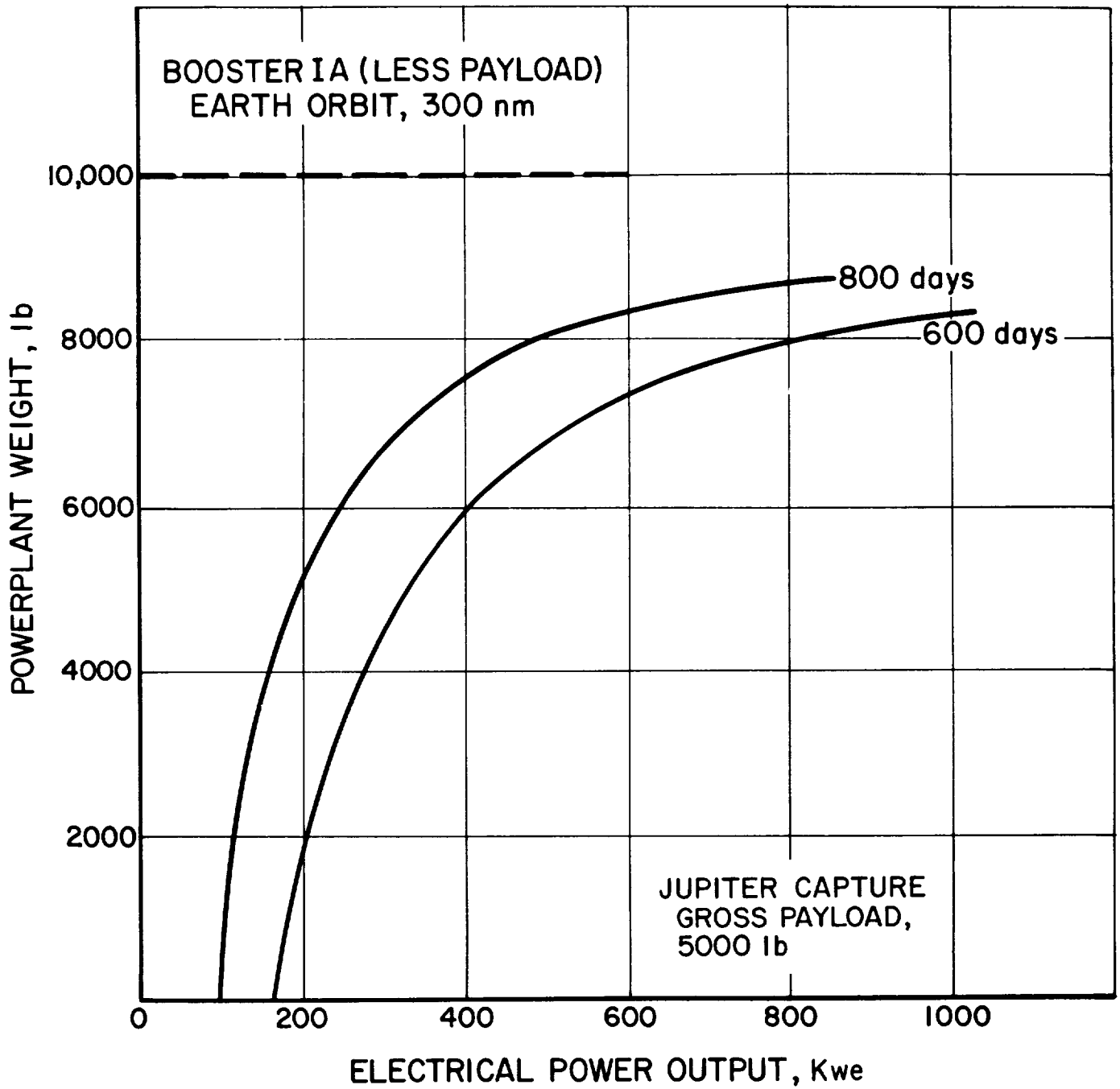


Fig. 4. Electrical powerplant requirements for a Jupiter capture mission aboard booster IA (Gross payload allowance is set at 5,000 lb)

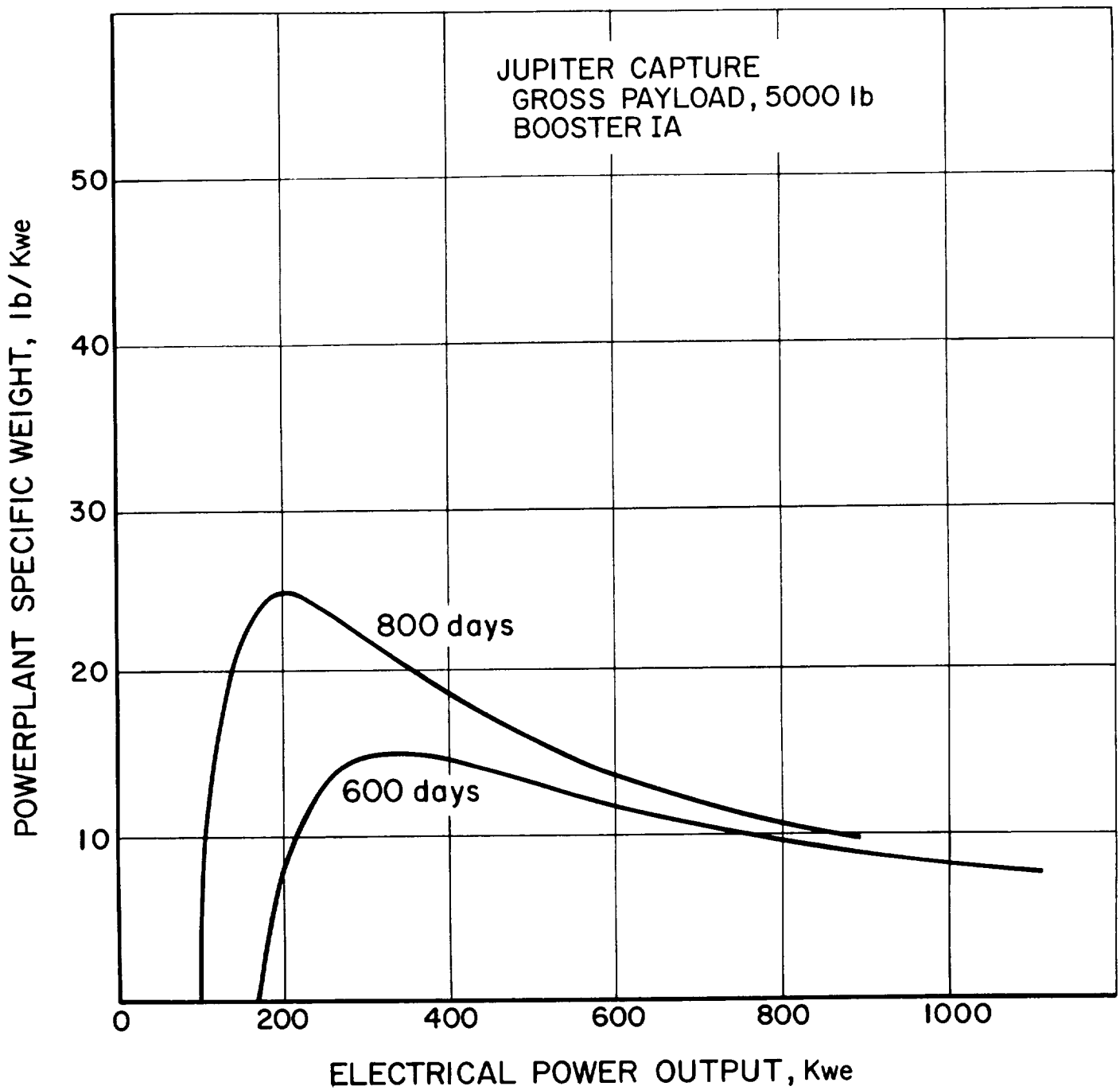


Fig. 5. Electrical powerplant requirements for a Jupiter capture mission aboard booster IA

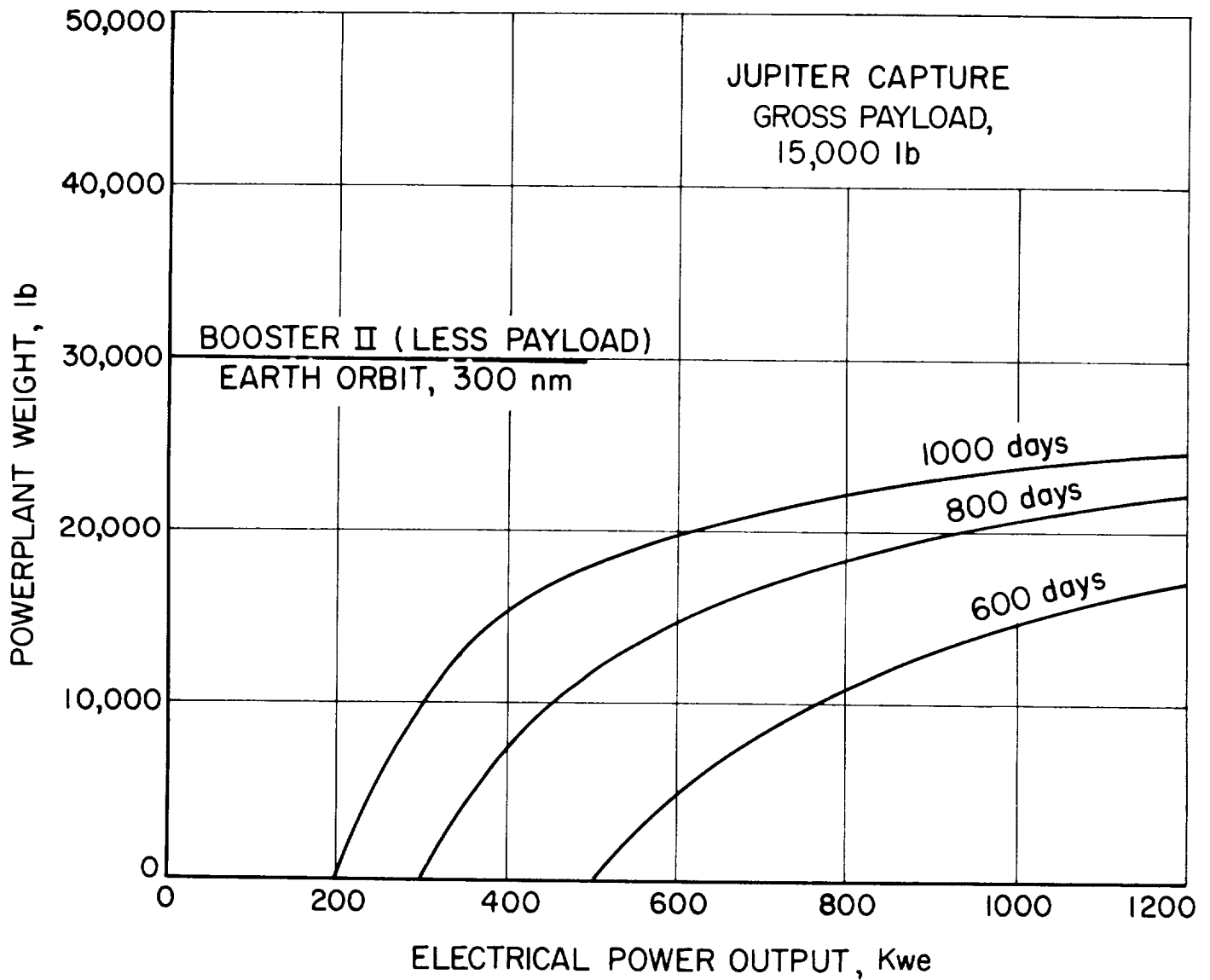


Fig. 6. Electrical powerplant requirements for a Jupiter capture mission aboard booster II (Gross payload allowance is set at 15,000 lb)

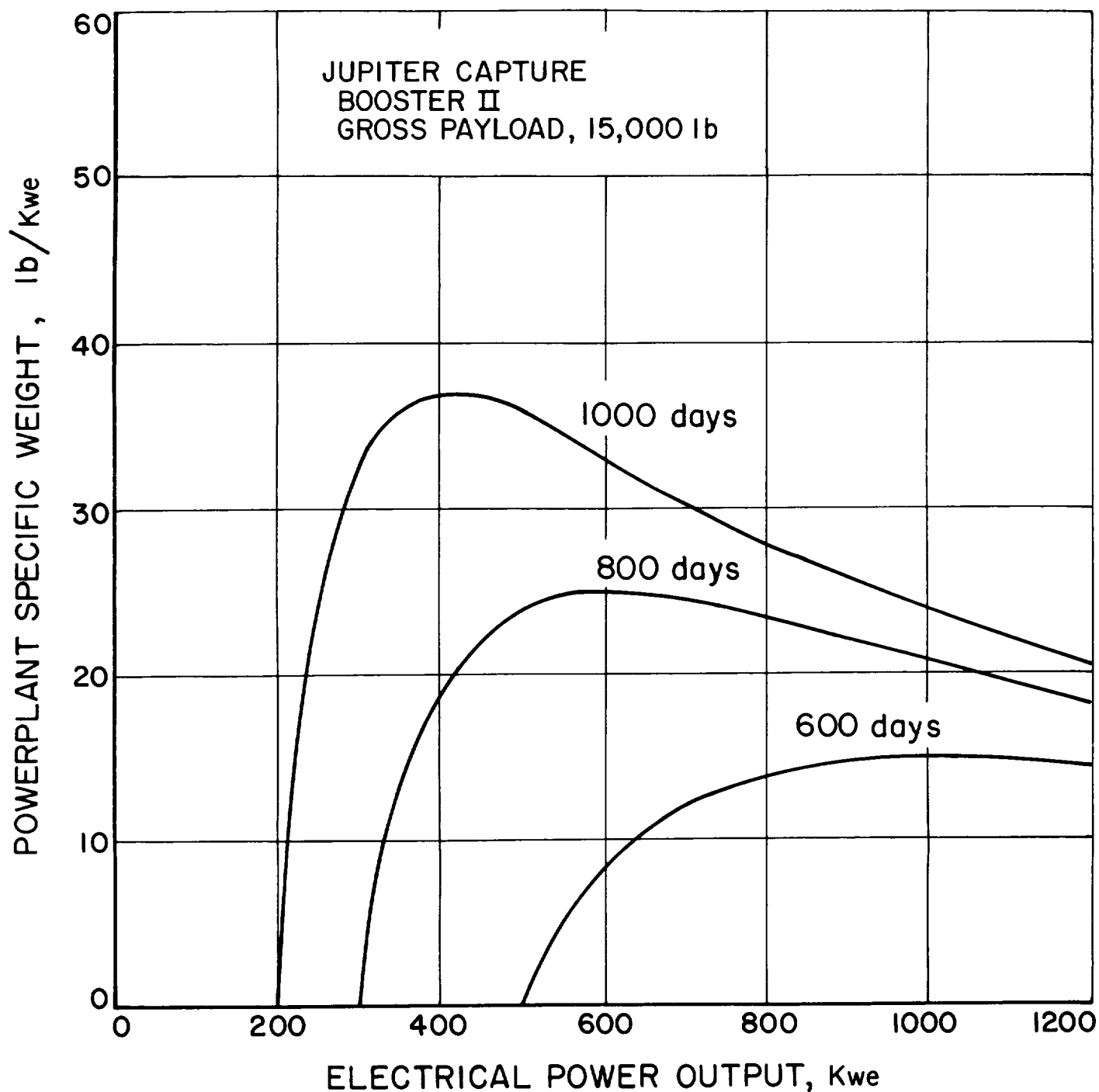


Fig. 7. Electrical powerplant requirements for a Jupiter capture mission aboard booster II

